Multi-year data-model evaluation reveals the importance of nutrient availability over climate in arctic ecosystem C dynamics

Efrén López-Blanco[1], Marcin Jackowicz-Korczynski[1,2], Mikhail Mastepanov[1,3], Kirstine Skov[1,4], Andreas Westergaard-Nielsen[4], Mathew Williams[5] and Torben R. Christensen[1]

[1] Department of Biosciences, Arctic Research Center, Aarhus University, Roskilde, Denmark
[2] Department of Physical Geography and Ecosystem Science, Lund University, Lund, Sweden
[3] Oulanka Research Station, Oulu University, Kuusamo, Finland
[4] Center for Permafrost (CENPERM), Department of Geosciences and Natural Resource Management, University of Copenhagen, Copenhagen, Denmark
[5] School of GeoSciences, University of Edinburgh, Edinburgh, UK

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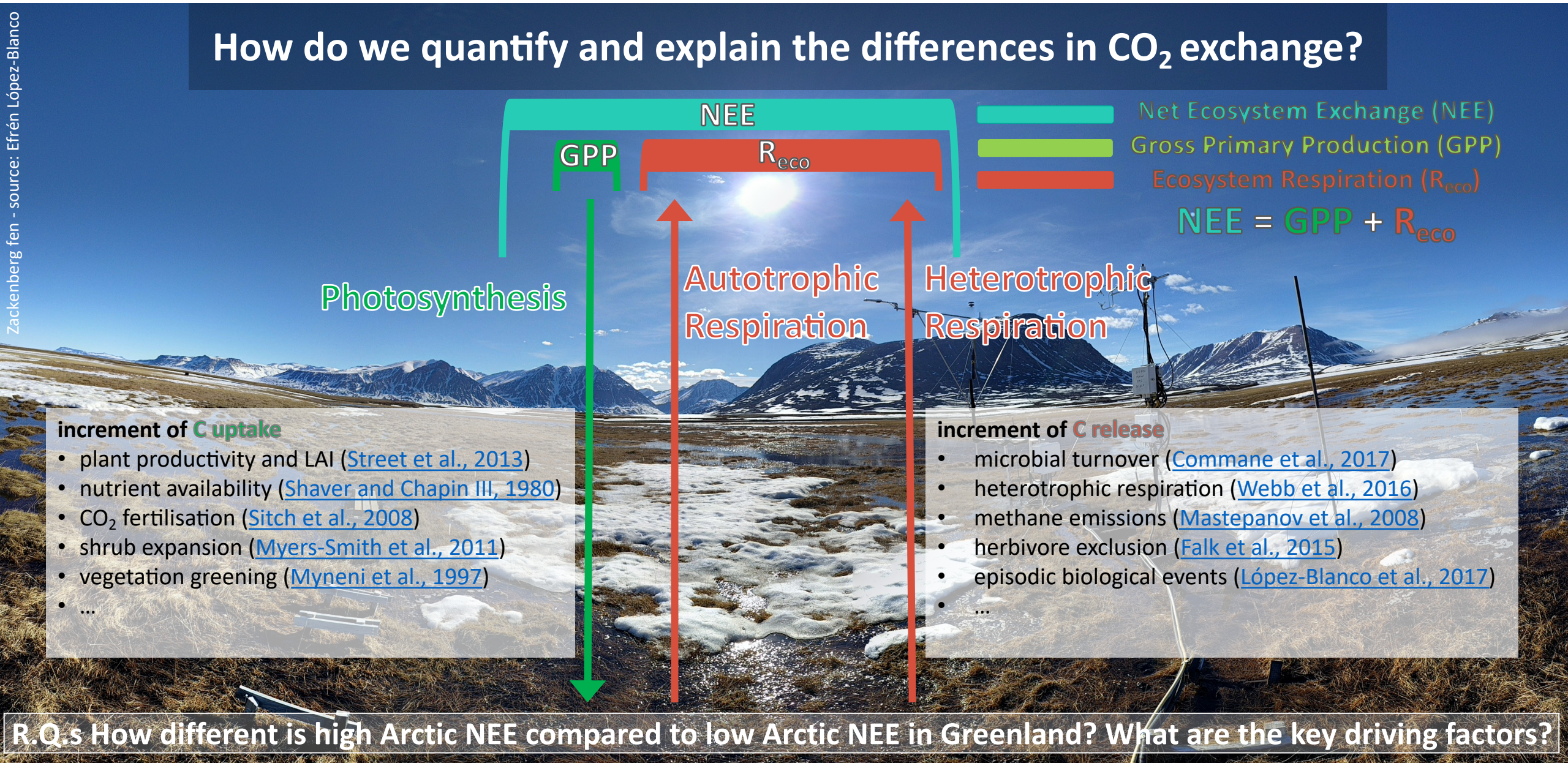
How do we quantify and explain the differences in CO_2 exchange?



Zackenberg fen - source: Efrén López-Blanco

increment of C uptake

- plant productivity and LAI (Street et al., 2013)
- nutrient availability (Shaver and Chapin III, 1980)
- CO_2 fertilisation (Sitch et al., 2008)
- shrub expansion (Myers-Smith et al., 2011)
- vegetation greening (Myneni et al., 1997)
- …

increment of C release

- microbial turnover (Commane et al., 2017)
- heterotrophic respiration (Webb et al., 2016)
- methane emissions (Mastepanov et al., 2008)
- herbivore exclusion (Falk et al., 2015)
- episodic biological events (López-Blanco et al., 2017)
- …

R.Q.s How different is high Arctic NEE compared to low Arctic NEE in Greenland? What are the key driving factors?

Study sites

ARCTIC ECOSYSTEM-ATMOSPHERE INTERACTIONS

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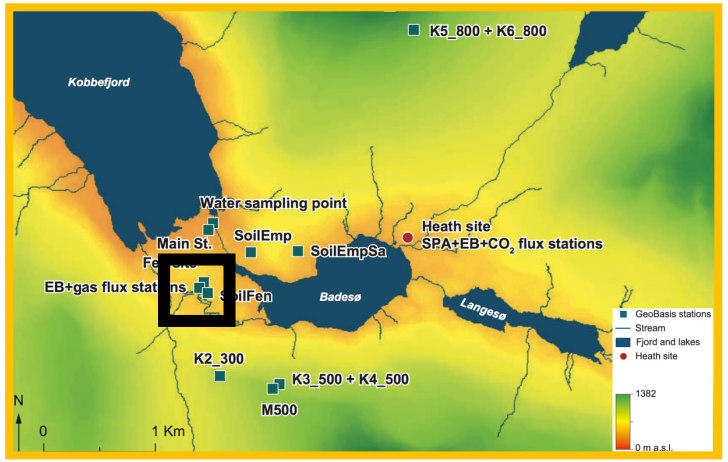
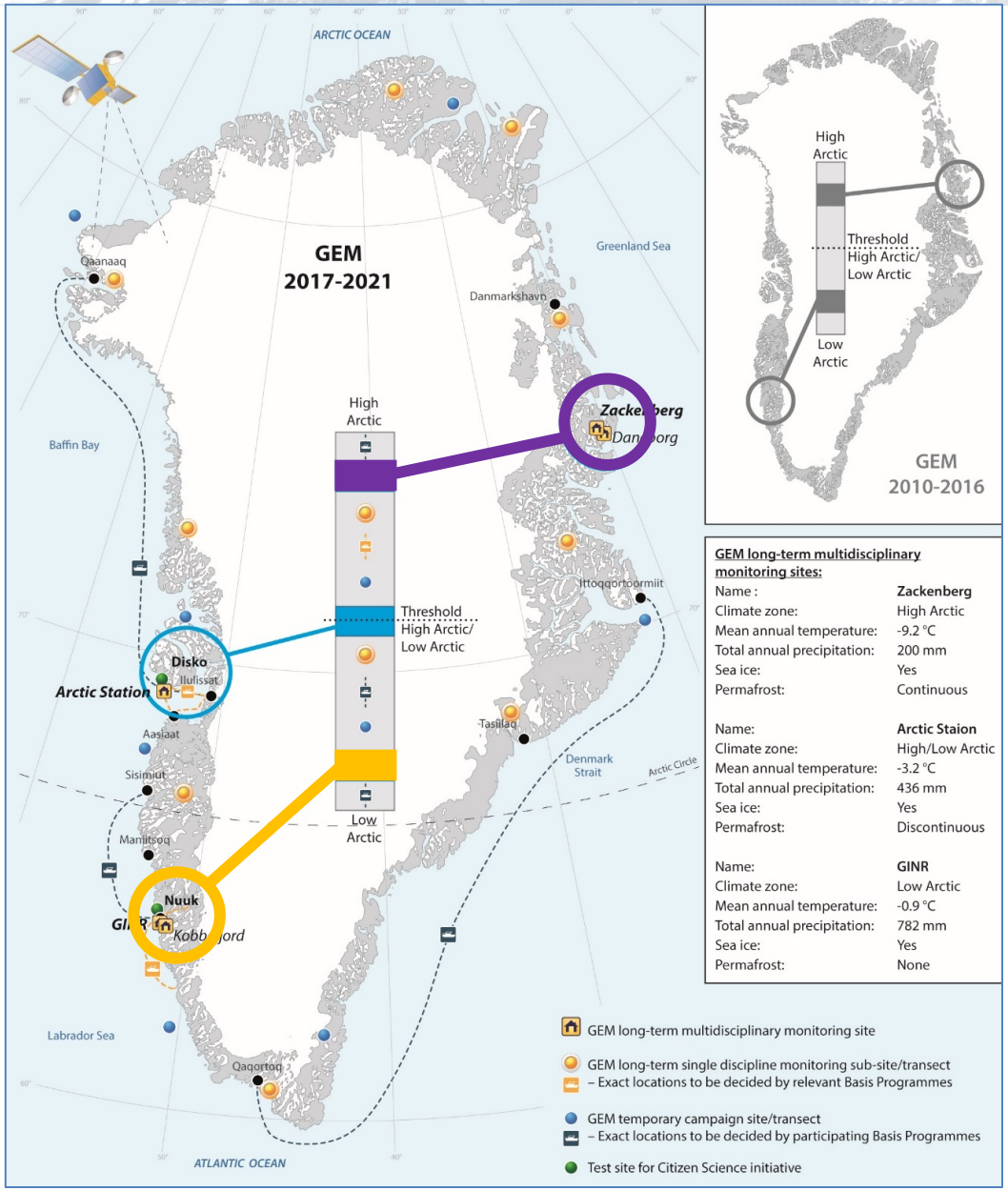
Kobbefjord fen

- Southwestern Greenland (**64°** 07’ N; 51° 21’ W)
- **Low Arctic** site with an average **T_{July} of 11-13° C**
- **No permafrost**
- ***Eriophorum angustifolium*** and ***Scirpus caespitosus***
- Sunlight hours from May to September **~ 14-21 hrs**



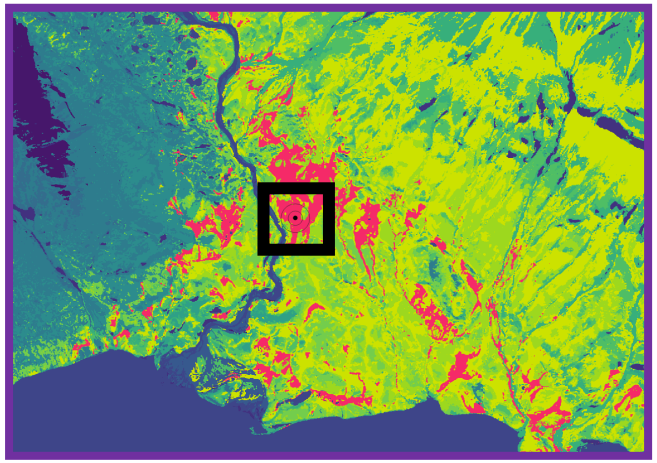


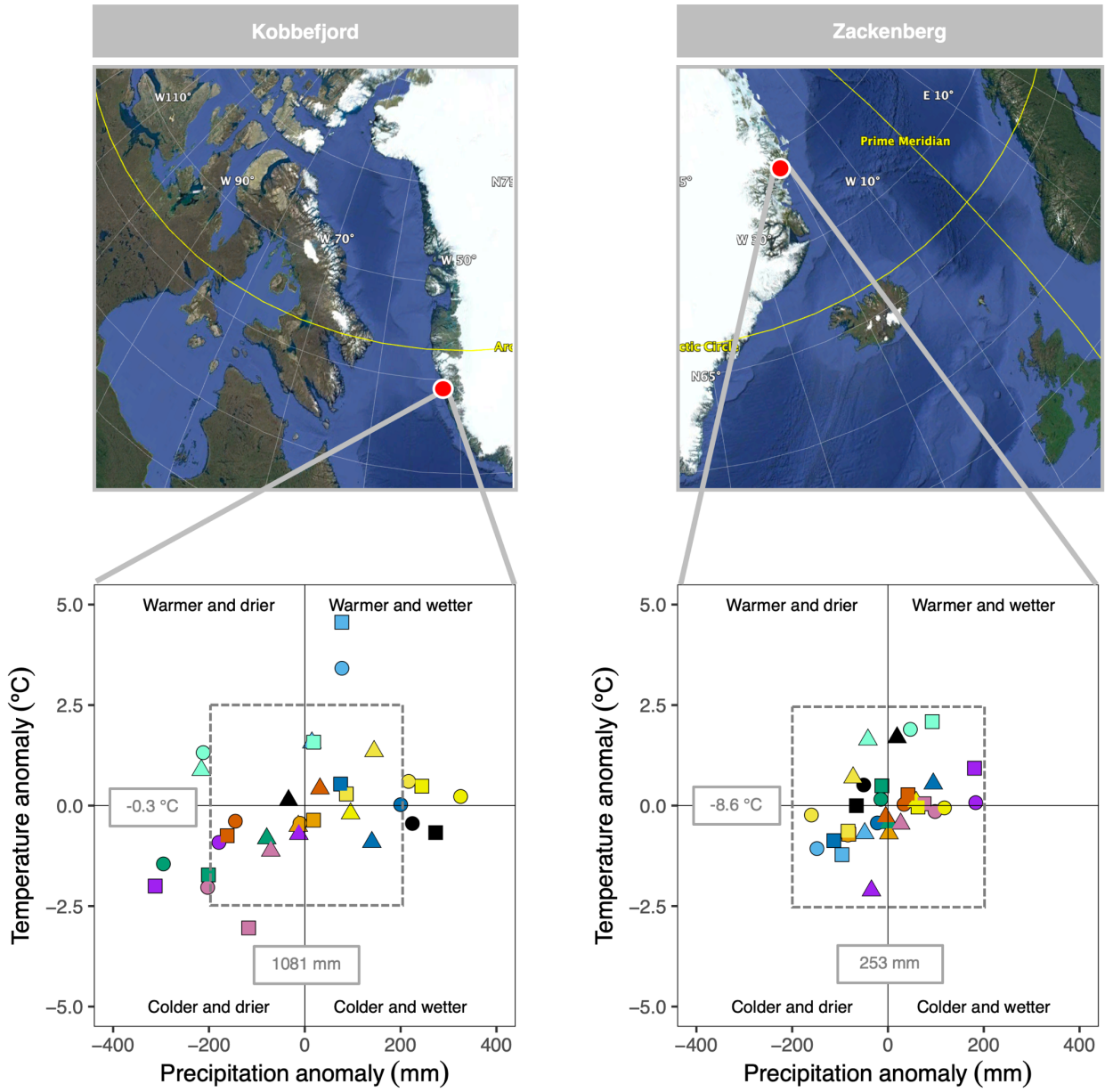
GEM long-term multidisciplinary monitoring sites:

Name :	**Zackenberg**
Climate zone:	High Arctic
Mean annual temperature:	-9.2 °C
Total annual precipitation:	200 mm
Sea ice:	Yes
Permafrost:	Continuous
Name:	**Arctic Staion**
Climate zone:	High/Low Arctic
Mean annual temperature:	-3.2 °C
Total annual precipitation:	436 mm
Sea ice:	Yes
Permafrost:	Discontinuous
Name:	**GINR**
Climate zone:	Low Arctic
Mean annual temperature:	-0.9 °C
Total annual precipitation:	782 mm
Sea ice:	Yes
Permafrost:	None

Zackenberg fen

- Northeastern Greenland (**74°** 28’ N; 20° 34’ W)
- **High Arctic** site with an average **T_{July} of 7-9° C**
- **Continuous permafrost**
- ***Eriophorum scheuchzeri*** and ***Dupontia psilosantha***
- Sunlight hours from May to September **~ 21-24 hrs**





Zackenberg, located 10° north of Kobbefjord, had lower interannual and interseasonal temperature and precipitation variability between 2008 and 2018

López-Blanco et al. (*in press*) [ERL]

Results

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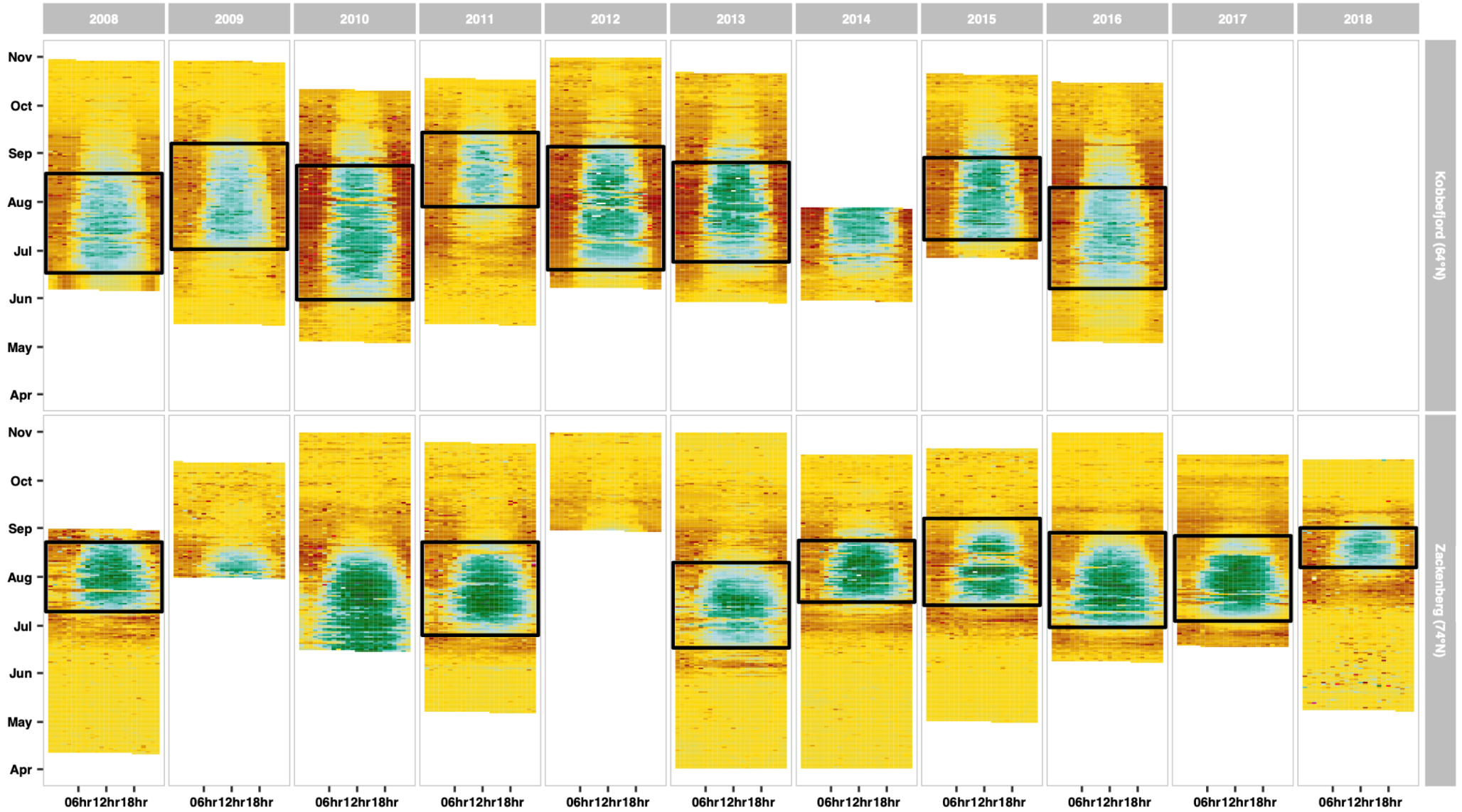


Zackenberg fen had a higher C sink strength (>170%) compared to Kobbefjord fen despite its higher latitude and markedly shorter growing season

μmol m^{-2} s^{-1}

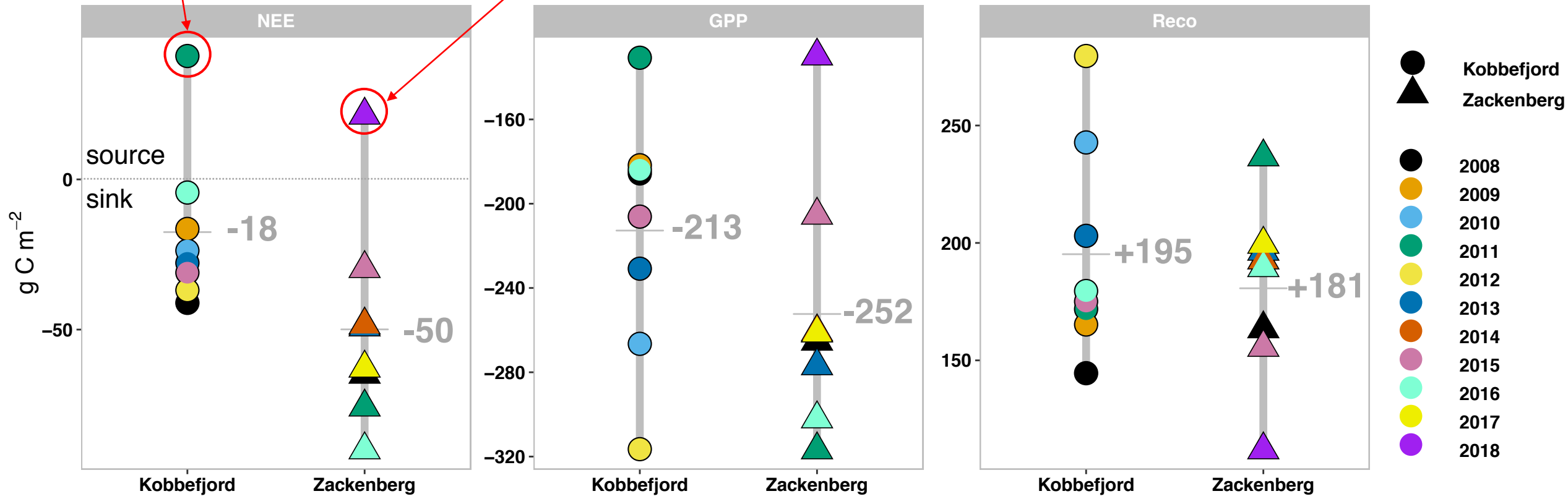
C uptake — C release

−10 −8 −6 −4 −2 0 2 4 6 8

Growing season

López-Blanco et al. (*in press*) [ERL]

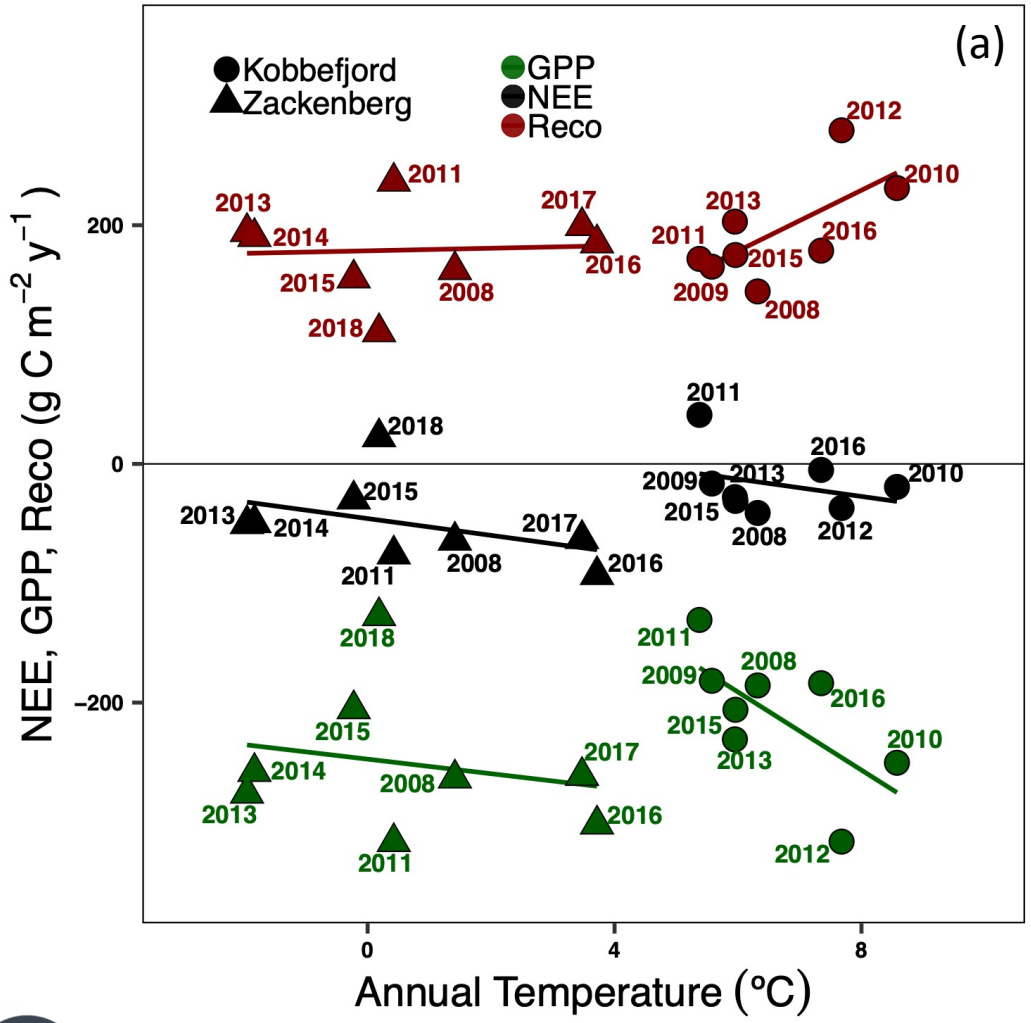
Moth outbreak ⚠ **Snow rich year** ⚠

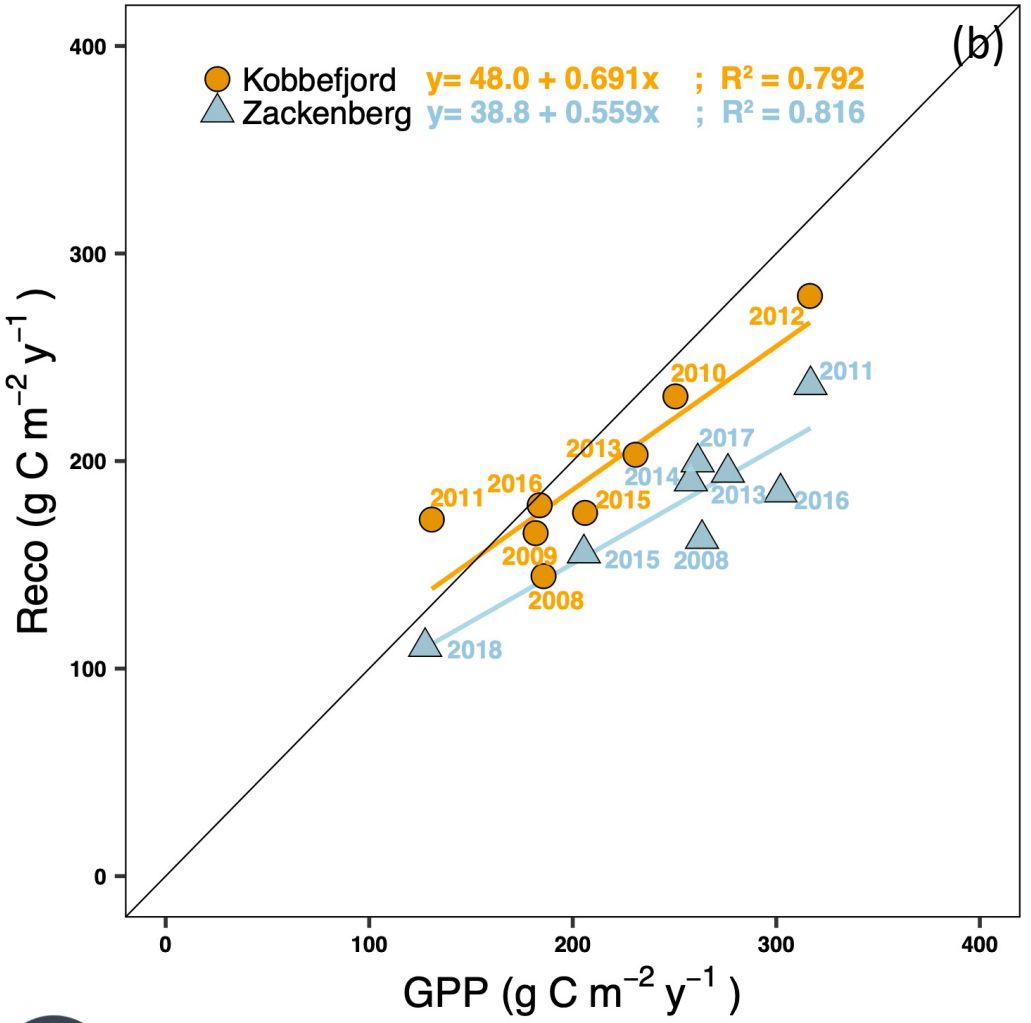


Zackenberg fen generally acted as a sink of CO_2 over the study period, with an average NEE of -50 g C m^{-2} yr^{-1} (range +21 to -90 g C m^{-2} yr^{-1}), more than twice as strong as Kobbefjord (-18 g C m^{-2} yr^{-1} with range of +41 to -41 g C m^{-2} yr^{-1})

In general, the higher C sink strength observed in Zackenberg is linked to larger photosynthesis (i.e. more negative GPP) rather than reduced respiratory losses (i.e. more positive R_{eco})

López-Blanco et al. (*in press*) [ERL]





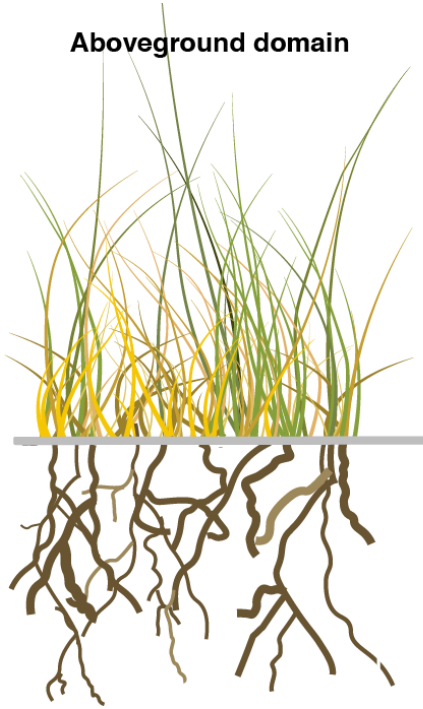
Lower sensitivity to annual air temperature from gross fluxes in Zackenberg (GPP slope = 6.1 g C m^{-2} yr^{-1} °C and R_{eco} slope = 1.1 g C m^{-2} yr^{-1} °C) compared to Kobbefjord (slope = 32.7 and 25 g C m^{-2} yr^{-1} °C)

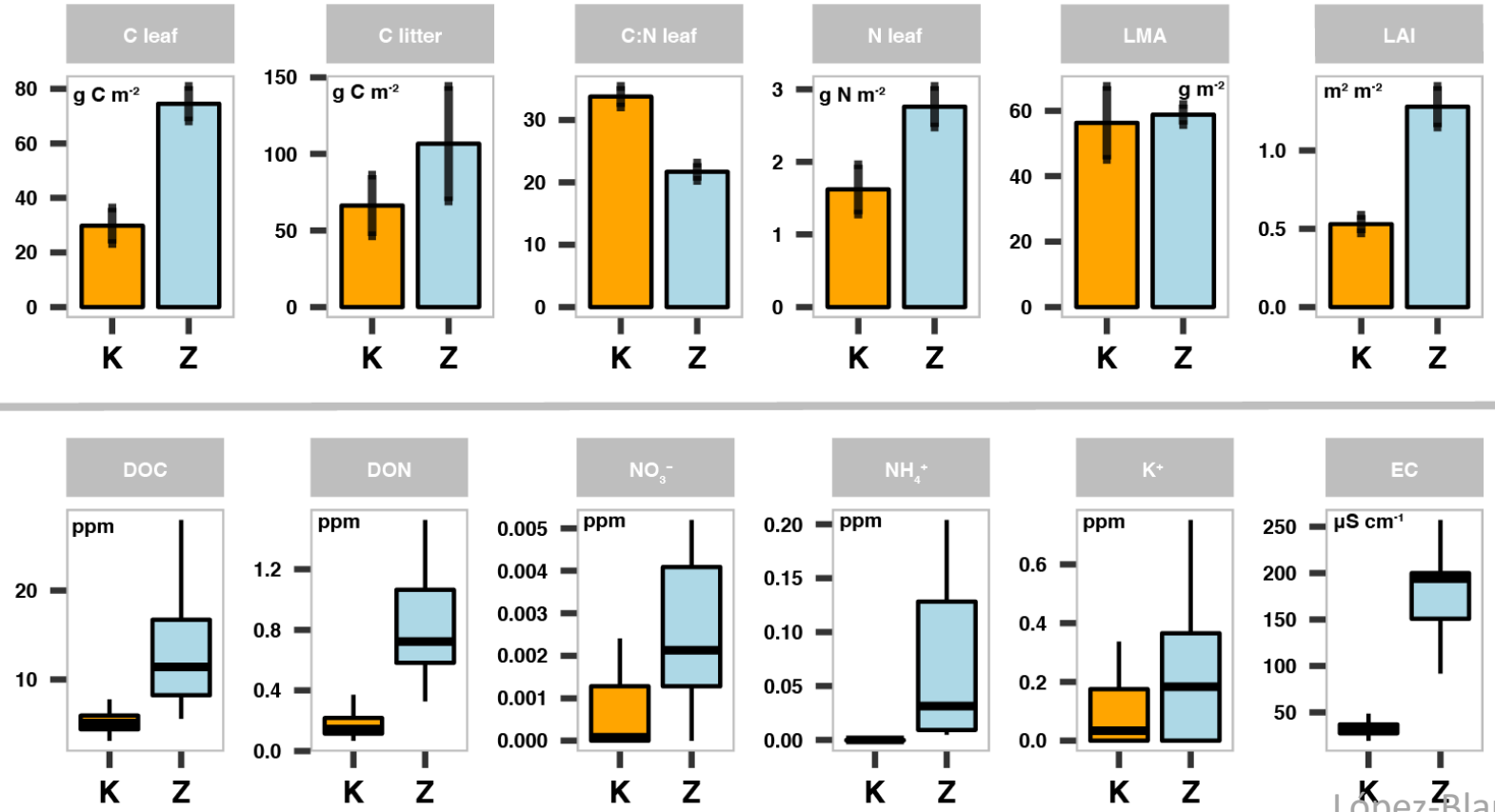
Similar compensatory effect between photosynthesis and respiration. However, the contribution to NEE in Zackenberg was dominated by GPP (39 g C m^{-2} yr^{-1} more than Kobbefjord) compared to R_{eco} (14 g C m^{-2} yr^{-1} less)

López-Blanco et al. (*in press*) [ERL]

Why Zack-Fen has higher C sink strength across shorter growing seasons?

- Is Zackenberg **nutrient richer**? Aboveground? Belowground?





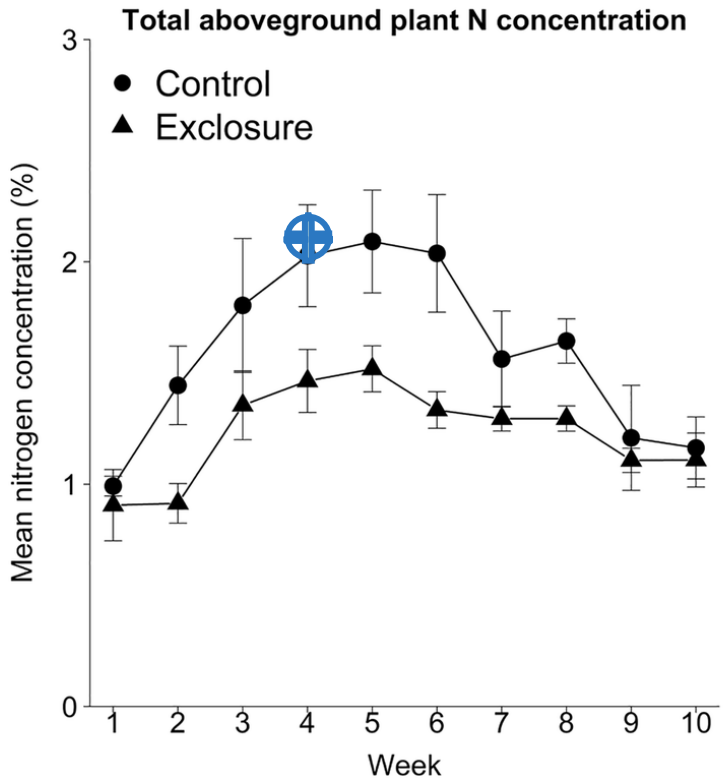
The new in-situ information retrieved from the 2019 sampling campaign shows systematic larger C stocks, leaf mass per area (LMA), leaf N, leaf area index (LAI), and plant quality (C:N ratio) in the Zackenberg fen

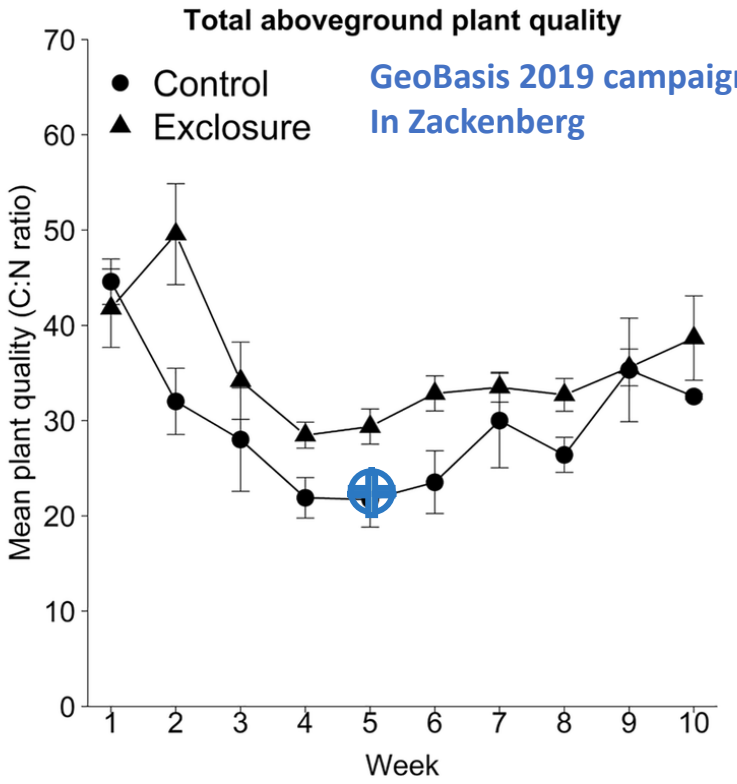
The water chemistry data from the first 50cm of Zackenberg fen topsoil show consistent higher levels of Dissolved Organic C (DOC), Dissolved Organic N (DON), nitrates (NO_3^-), ammonium (NH_4^+), potassium (K^+) and electroconductivity (EC) during the 2015-2017 period

López-Blanco et al. (in press) [ERL]

Why Zack-Fen has higher C sink strength across shorter growing seasons?

- Is Zackenberg **nutrient richer**? Aboveground? Belowground? Muskox influence?





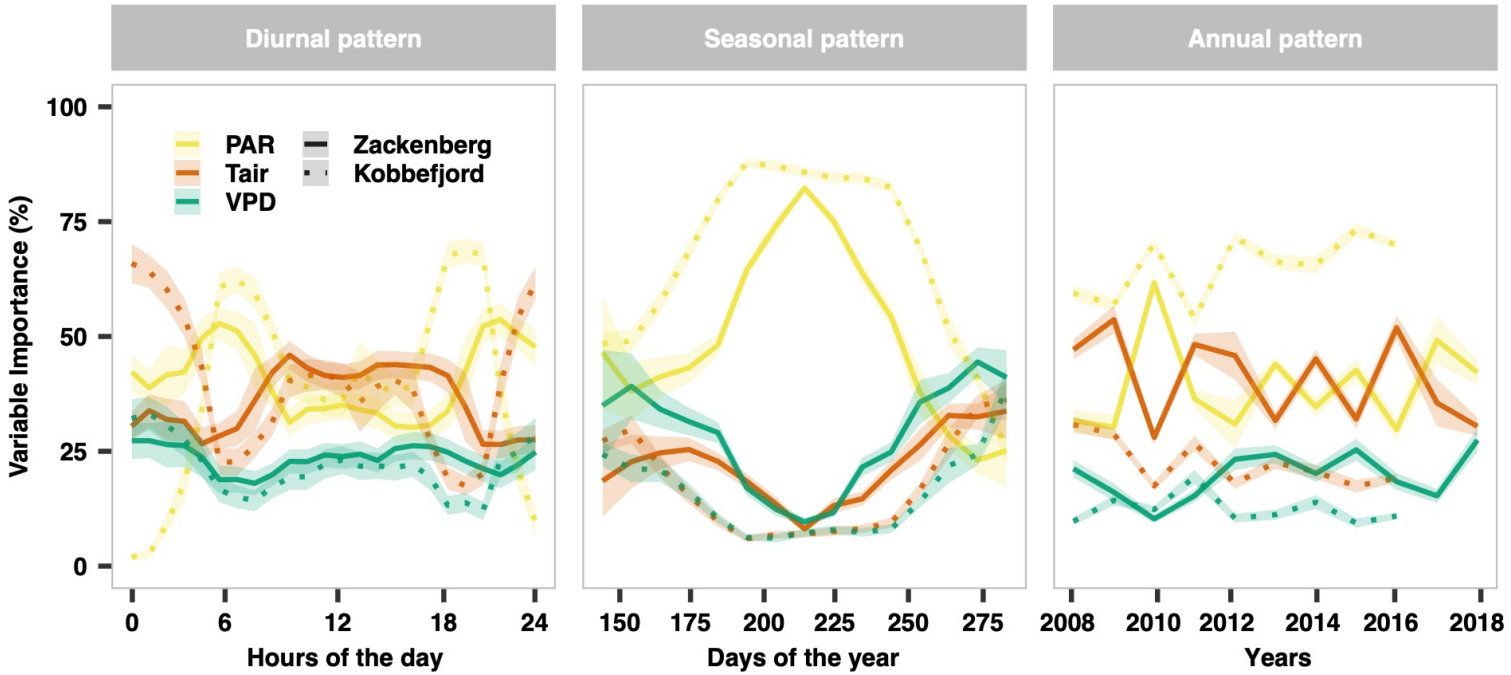
The presence of muskox in Zackenberg has been associated with significant increases of N concentration and enhanced plant quality (i.e. C:N ratio)

Mosbacher et al. (2018) [Ecosystems]

Why Zack-Fen has higher C sink strength across shorter growing seasons?

- Is Zackenberg **nutrient richer**? Aboveground? Belowground? Muskox influence?

- Is the C sink strength enhanced due to **longer light hours**?



Using a random forest machine-learning technique the importance of photosynthetic active radiation to NEE at diurnal, seasonal and annual scales in Zackenberg (with 24-h daylight in the arctic summer) was not larger than in Kobbefjord.

For a full description about the random forest technique, see López-Blanco et al. (2017).

López-Blanco et al. (2017) [BG]
López-Blanco et al. *(in press)* [ERL]

Why Zack-Fen has higher C sink strength across shorter growing seasons?

- Is Zackenberg **nutrient richer**? Aboveground? Belowground? Muskox influence?

- Is the C sink strength enhanced due to **longer light hours**?

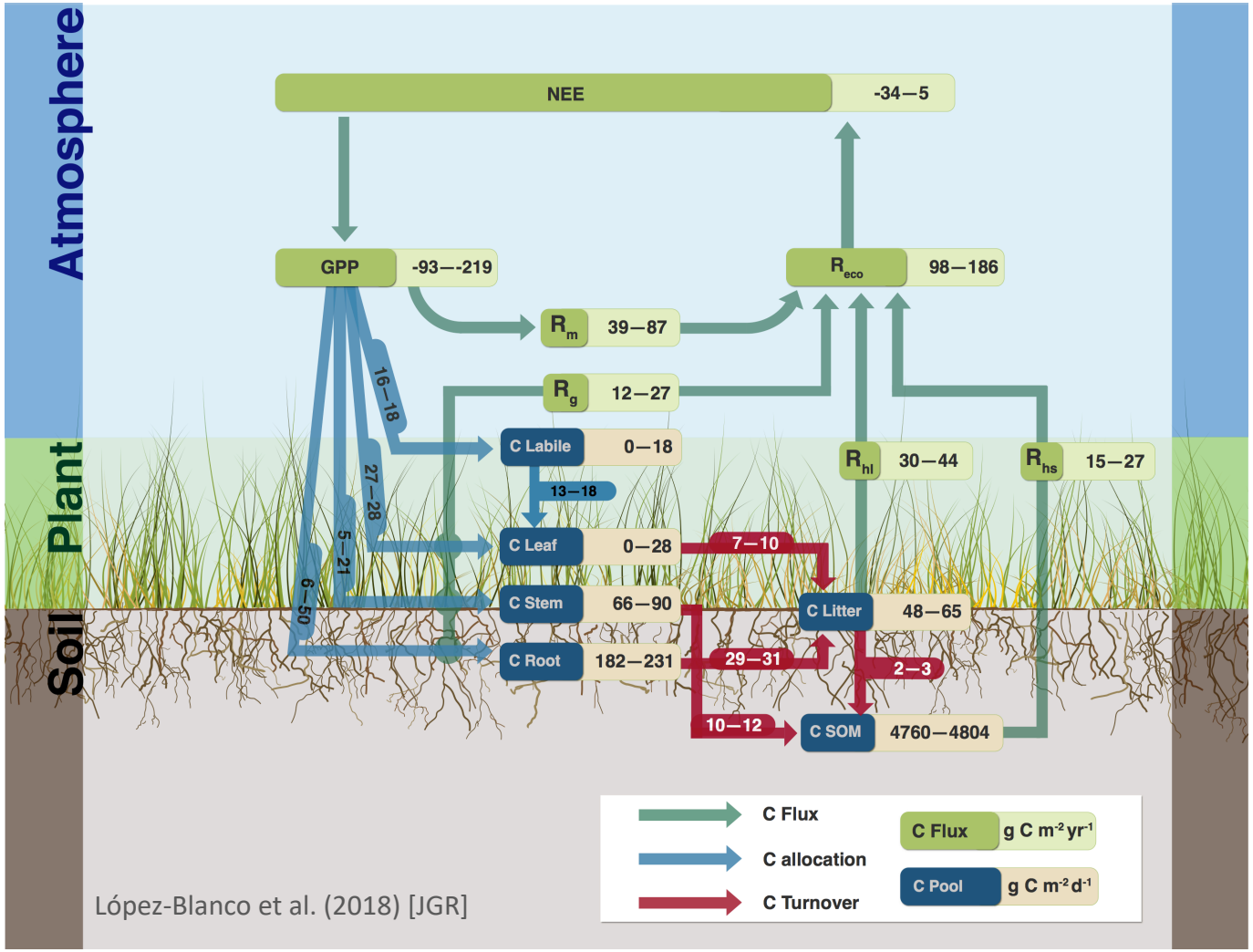
- Is the **hydrology/parent material/permafrost** playing a key role?

1. N availability is controlled by the **lateral transport** from surrounding slopes (Rasmussen et al., 2020)
2. The **parent material** in Kobbefjord is dominated by **slow-weathering Precambrian gneisses** (Søndergaard et al., 2012), while in Zackenberg is dominated by **faster-weathering basalts and sedimentary deposits** (Cable et al., 2018)
3. **Permafrost may help to retain N availability** more concentrated than permafrost free areas (Olefeldt et al., 2014)
4. **Permafrost soil release more nutrients** than active layer soils (Reyes & Lougheed, 2015; Keuper et al., 2012), releasing plant-available N and ultimately stimulating plant productivity

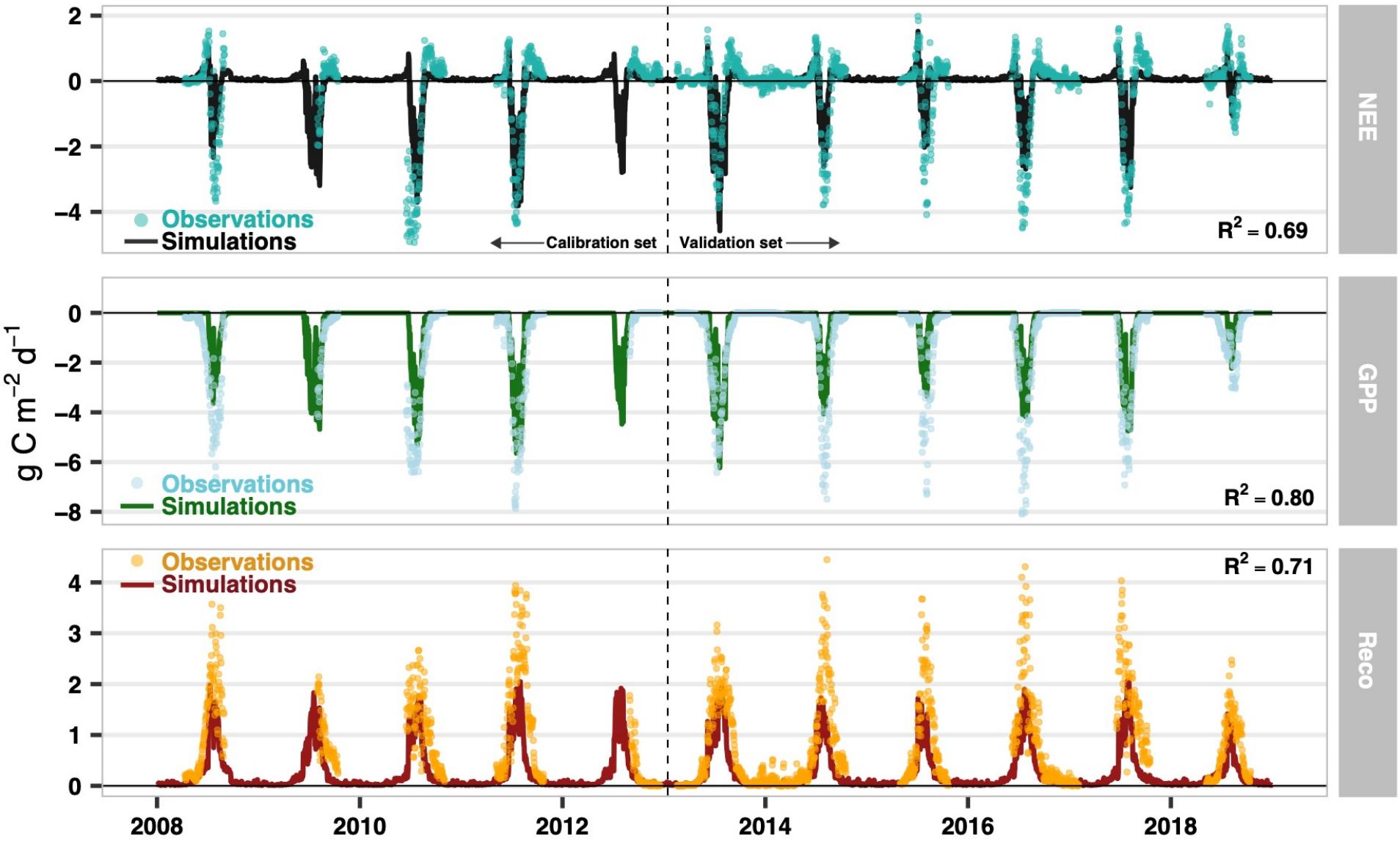
Soil Plant Atmosphere (SPA) model

- **SPA** (Williams et al., 1996, 2000…)
  - High vertical mechanistic point model
  - Multilayer canopy (10) and soils (20)
  - High temporal resolution (30 min)
  - Leaf-level scale of parametrization
  - Canopy-level prediction
  - Can be validated with eddy flux data

- **DALEC** (Williams et al., 2005)
  - Box carbon model
  - Phenology and carbon dynamics:
    - C allocation, litterfall, decomposition
  - Model imbedded in SPA



López-Blanco et al. (2018) [JGR]



The SPA model can realistically characterise 11 years of data from the Zackenberg fen with model setup varying according to *in-situ* biomass and tissue N data.

At Zackenberg the daily aggregated NEE, GPP, and R_{eco} matched the independent summertime field observations for the validation period (2013-2018).

López-Blanco et al. (*in press*) [ERL]

Importance of field data (!) in C cycle modelling

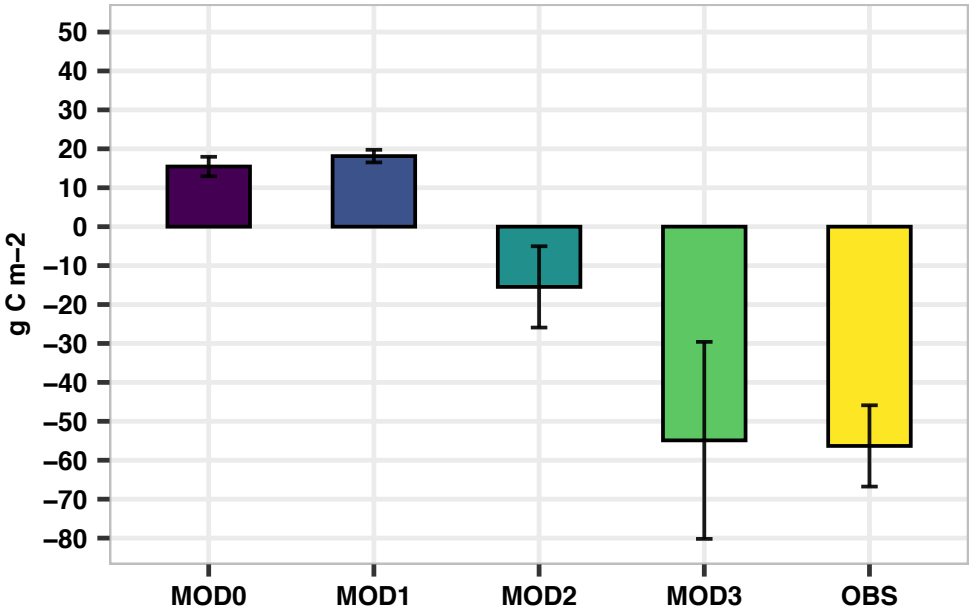
Parameter	Unit	Function	Value	Source	SI-NEE	SI-GPP	SI-R_{eco}
…	…	…	…	…	…	…	…
Turnover rate of labile pool	$hour^{-1}$	CC	0.0022	Tuned	0.629	0.131	0.075
NPP allocated to foliage	fraction	CC	0.7	Smallman et al., 2013	0.713	0.147	0.084
Fraction of leaf loss to litter	fraction	CC	0.3	Tuned	0.963	0.166	0.077
NPP allocated to roots	fraction	CC	0.7	Smallman et al., 2013	1.052	0.033	0.080
Mineralisation rate of SOM	$hour^{-1}$	CC	0.000001	Tuned	1.259	0.000	0.140
Rate coefficient for Vcmax	µmol C g N^{-1} s^{-1}	PT	14	Smallman et al., 2013	1.334	0.227	0.104
Initial SOM C	g C m^{-2}	IC	4800	Hugelius et al., 2013	1.346	0.001	0.150
Initial root C	g C m^{-2}	IC	200	Field data	1.584	0.047	0.124
Average foliar nitrogen	g N m^{-2}	CS	1.61	Field data	3.154	0.916	0.667
Maximum foliar carbon stock	g C m^{-2}	CC	28	Field data	3.868	0.922	0.595
Rate coefficient for Jmax	µmol C g N^{-1} s^{-1}	PT	36	Smallman et al., 2013	4.432	0.786	0.369
Leaf mass per area	g C m^{-2}	CS	56.27	Field data	4.546	1.137	0.769

Ranking table listing the sensitivity indices (SI) for NEE, GPP and R_{eco} subject to the average ±10% change of each of the 36 ecosystem parameters in SPA (here only shown the 12 most sensitive).

López-Blanco et al. (*2018*) [JGR]

SPA can generate a system consistent with Zackenberg fluxes only by parameterisation based on the biomass sampling data from the field campaign.

Using the initial calibration from Kobbefjord under Zackenberg climate fails to simulate annually aggregated NEE within the observation's range.



Cumulative NEE in Zackenberg across 11 years (2008-2018) using different experimental setups in SPA (MOD0-3):

- **OBS: EC NEE observations**
- **MOD0: Zackenberg climate forcing using López-Blanco et al. (2018)'s model calibration;**
- **MOD1: MOD0 including snowmelt period retrieved from the time-lapse camera monitoring;**
- **MOD2: MOD1 including Q_{10} tuning;**
- **MOD3: MOD2 including *in-situ* C and N information.**

López-Blanco et al. (*in press*) [ERL]

Take home messages

- **Zackenberg fen has a significant higher C sink strength** during repeatedly shorter growing seasons.

- **Zackenberg is a nutrient richer fen** - the increased C uptake strength is associated with:

  A. higher C and N stocks and enhanced plant quality.
  B. higher levels in soils of DOC, nutrients such as DON, NO_3^-, NH_4^+, K^+, and electroconductivity.

- Growing season limitations of plant phenology on net C uptake **have been more than counterbalanced** by the increased leaf nutrient content at the Zackenberg site .

- A **simple set of parameters** from one single field campaign **was enough to explain a significant portion of the C flux variability** at very high temporal resolution in a very complex ecosystem.

- **More sites for high-temporal monitoring of terrestrial C dynamics are needed** to establish robust baselines for model calibration and validation, thereby **underpinning ecological forecasting techniques**

More details in https://doi.org/10.1088/1748-9326/ab865b

Thanks for the attention! Questions?

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